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ROYAL AIRCRAFT ESTABLISHMENT
(FARNBOROUGH)

8819

TECHNICAL NOTE No: MECH. ENG. 249

REVIEW ON Dec. '87

**CONTINUOUS-ROD WARHEAD
LETHALITY TRIALS AGAINST
STATIC AIRCRAFT TARGETS
(RODS 3/16 inch x 3/16 inch CROSS-SECTION)**

by

D.A.HANCOCK, A.M.I.Mech.E., A.F.R.Ae.S.

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Technical Note No. Mech Eng 249

December, 1957

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ROYAL AIRCRAFT ESTABLISHMENT, FARNBOROUGH

Continuous-Rod Warhead Lethality Trials
against Static Aircraft Targets
(Rods $3/16$ inch \times $3/16$ inch cross-section)

by

D. A. Hancock, A.M.I.Mech.E., A.F.R.Ae.S.

RAE Ref: ME/B3/9072/DAH

SUMMARY

This Note records the results of six static detonations of continuous-rod warheads (rod cross-section $3/16$ inch \times $3/16$ inch) against aircraft targets at ground level. An indication of the kill probabilities against aircraft structures is given. The warhead appears to be more damaging against structures with distributed load-carrying members than against those with concentrated primary structural members. In general, the standard of terminal lethality of the warhead does not seem sufficiently high for a front-line defence weapon.

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1 Introduction

1.1 During development trials of various types of "second-generation" warheads for anti-aircraft guided missiles, firings were made with a $\frac{3}{16}$ inch square section continuous-rod type of warhead against a number of static aircraft targets.

1.2 The particular type and size of warhead used in these trials was developed as a research item, and the firings, which were part of the normal development trials conducted by A.R.D.E., were used also to provide data on aircraft structural vulnerability to attack by small-section continuous-rod.

1.3 This Note discusses and records the aircraft damage aspects of these trials, which were made at the Proof and Experimental Establishment, Shoeburyness, during 1956.

1.4 Comparable trials have been made with a warhead employing a $\frac{1}{4}$ inch square section continuous-rod. These trials will be discussed in a separate report.

2 Trials Programme

2.1 Six similar warheads were detonated. In each case an array of targets was used, consisting of a number of aircraft sections mounted in various attitudes in a circular layout of nominally 15 ft radius around the warhead. In most cases the targets were supported by means of guy-wires or scaffolding. Rod velocities were recorded by an Argon Lamp Chronograph, using four screens, the warhead being detonated electrically from a contact on the firing pendulum of the chronograph.

2.2 The damage to each target is detailed in this Note, and where applicable, a kill assessment given in Category 'A', i.e. the aircraft will fall out of control within five minutes of being hit. The assessments are based on structural considerations only, no allowance being made for fire risks or component damage.

3 Description of Warhead

3.1 A continuous-rod warhead consists of a charge of H.E. surrounded by a large number of short rods of steel. Each rod is joined at one end to its immediate neighbour in zig-zag form, so that when it is expanded outwards it can form a ring of ever-increasing diameter, until a maximum size is reached and the ring breaks up. It is, in effect, a more refined form of the fragmenting warhead, in that the casing fragments are joined together and the area of damage on the target is concentrated.

3.2 The warheads used in these trials were made to A.R.D.E. design No. D2(L)11639/G.F. In each trial a warhead was mounted vertically on a stand, with its C.G. about 7 ft above ground level, and detonated statically. A view of one erected prior to detonation is shown in Fig.1. The overall diameter of this warhead was eight inches, and it had a total filling weight of 9 lb RDX/TNT 60/40. The rod itself was of square cross-section, $\frac{3}{16}$ inch \times $\frac{3}{16}$ inch. Central initiation was adopted, using two No.33 electric detonators.

3.3 These warheads had, before the trials, been developed to a point where rod signatures were reasonably continuous at about one third of the expected maximum effective hoop radius [i.e. $(n\ell - \text{length of welds}) + 2\pi$, where n = number of rods and ℓ = length of each rod]. It was later established that the maximum effective hoop radius was about 23.5 ft.

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4 Targets

4.1 The number of suitable targets available for the trials was very limited, but because of the localised nature of the damage it was possible to use the same targets in more than one layout. For this same reason, undamaged parts of targets that had been used in trials of other weapons were included.

4.2 Valiant, Victor, Javelin and Comet aircraft wings were attacked to determine the effectiveness of this type of warhead against structures of fairly modern design. The last three of these types incorporated high-strength light-alloy materials, which were also of interest from an "extent of damage" viewpoint.

4.3 Similarly, Lancaster aircraft wings and rear centre portions of fuselage, B.29 fuselage sections, and replica targets (R4B), all of which incorporate heavy members in the form of longerons or spar-booms, were used to determine the effects on these of rod attack.

4.4 One section of a Valiant fuselage was available and this represented the modern trend in fuselage design in which the load is distributed throughout the skin and stringers.

4.5 Lancaster aircraft wings were also attacked at the fuel tank sections, to study the effects of hydraulic shock waves caused by rod impact.

4.6 Since they have a relatively tough leading-edge structure, Spitfire aircraft wings were included, to investigate the effects of rods approaching from around the head-on direction.

4.7 The target layouts for the six firings are shown diagrammatically in Figs. 2 to 7 respectively. A view of a typical layout, before firing, is shown in Fig. 8.

5 Results

5.1 The results of the firings are detailed in Table I, and the damage caused to representative individual targets is shown in Figs. 9 to 21.

5.2 The rod velocities recorded were within the range 3,170 ft/sec to 3,300 ft/sec.

6 Discussion of Results

6.1 In general the results showed that the warhead was effective in producing a continuous cut in aircraft light structures such as the skinning, but broke up on coming into contact with relatively strong structural members, inflicting little apparent damage on them. This was the primary factor governing the kill assessments given in Table I.

6.2 The warhead proved rather more effective against the later types of aircraft wing structure, in which loads are fairly well distributed, than against the older structural designs in which concentrated load carrying members are employed. For the particular positions and directions of attack selected, kills were inflicted on the Victor, Valiant, Javelin and Comet wings, but not on the Lancaster wing. It must not be assumed from this that kills would necessarily be obtained from strikes at any position, or from any direction, on the four modern types mentioned.

6.3 Only one example of "shatter-cracking" in the high-strength alloy skins was noted, this being on the exit side of the attack against a Comet wing (see Fig. 15). None of the wing sections was under load at the time of the attack; it is not known whether this would have any effect on the results obtained.

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6.4 As in the case of the wings, the modern type of fuselage (Valiant) proved rather more susceptible to damage than did the older types (Lancaster and B.29) because of the presence of heavy longerons in the older types.

6.5 The presence of liquid in a wing structure appeared to reduce the structural damage on the exit side, the rods being retarded or brought to rest in the liquid. The entry side damage was slightly increased, usually in the form of skin bulging, due, presumably, to the pressure wave. It is likely that the configuration of the liquid container (fuel tank) and the amount of liquid present will affect the extent of the damage; further trials would be needed to elucidate these effects.

6.6 The attacks against the Spitfire wings showed that rods approaching normal to the leading-edge will generally be broken and inflict very little damage. However even an approach angle as small as 10° - 15° from the normal is sufficient to allow the rod to inflict extensive chordwise damage on this wing structure.

7 Conclusions

7.1 The results of the present series of trials indicate that a 3/16 inch square section continuous-rod, with a striking velocity of about 3,200 ft/sec, and with the rod unbroken at impact, is:-

- (a) More damaging against aircraft structures without heavy concentrated members (such as Victor, Valiant etc.) than against aircraft with large spar booms and heavy longerons (such as the Lancaster).
- (b) May inflict severe chordwise damage to the wing or tailplane of a directly approaching target when impacting on the leading-edge provided that it is at an angle greater than 10° - 15° to the normal. With strikes more near the normal the damage is unimportant.
- (c) A little more damaging against liquid-filled structures than empty structures.

7.2 In general, it appears from these trials that for the 3/16 inch square section continuous-rod warhead the overall standard of terminal lethality is not sufficiently high to be acceptable for a front-line defence weapon.

Attached:- Table I
Fig.1, Figs.8-21 Neg.Nos. 134,414 to 134,428
Figs.2 to 7, SME 81473/R to SME 81478/R
Detachable Abstract Cards

Advance Distribution

DG/GW		DDGG		Director,RAE
D/GWRD	Action	DDG(RAF)		DDRAE(A)
DGWTD		DA Arm		DDRAE(E)
DA(Mech)		Sec OB	2	GW Dept,RAE
DG of A		GW/P&W		Arm Dept,RAE
DWR		DARDE		Structures Dept,RAE
DDGFS		TIL	60	RAE Library
				RAE Bedford Library
				Pats 1/RAE

TABLE I

Record of Damage to Aircraft Targets

Target	Damage	A/C Kill Assessment
1. <u>Valiant Fuselage</u>		
(a) Target 1, Layout No. 3. Impact at normal 45° across fuselage.	15 ft cut (35% of circumference) in skinning (18 SWG and 16 SWG). 26 stringers (18 SWG) severed (35% of total). 6 frames (18 SWG) severed. $\frac{1}{8}$ in. groove in bomb bay longeron.	50% 'A'
(b) Target 2, Layout No. 3. Impact at normal across fuselage.	12 ft cut (35% of circumference) in skinning. 50 stringers severed (65% of total). 1 frame severed in 3 places. 5 floor stiffeners severed.	100% 'A'
(c) Target 3, Layout No. 4. Impact at normal across fuselage.	13 $\frac{1}{2}$ ft cut (40% of circumfer- ence) in skinning. 52 stringers severed (68% of total). Bomb bay starboard longeron severed. Bomb bay port longeron 50% severed.	100% 'A'
2. <u>Valiant Wing</u>		
(a) Target 4, Layout No. 6. Impact at normal across wing.	7 ft cut (70% of chord) in upper surface skinning (12 SWG). 9 stringers severed + 10 x 50% cut (18% of total). L.E. skinning (16 SWG) com- pletely severed, including stringers. Front spar top boom and front spar web severed, front spar lower boom 50% severed.	100% 'A'
3. <u>Victor Wing.</u>		
(a) Target 5, Layout No. 6. Impact at normal across wing.	9 ft 9 ins cut (100% of chord) in upper surface sandwich skinning (14, 16, 14 SWG). Rear spar upper boom severed. Mid spar upper boom severed. Line of fragment holes across lower surface sandwich skinning.	100% 'A'

TABLE I (Contd)

Target	Damage	A/C Kill Assessment
<p>4. <u>Javelin Wing.</u></p> <p>(a) Target 3, Layout No.6. Impact at normal across wing.</p>	<p>6 ft 9 ins out (93% of chord) in upper surface (16 SWG). 3 ft out (40% of chord) in lower surface. Front spar web out to full depth. Both spar booms nicked. Bottom rear channel scored and cracked. No 'shatter'.</p>	<p>100% 'A'</p>
<p>5. <u>Comet Wing.</u></p> <p>(a) Target 1, Layout No.6. Impact at 75° to normal across wing.</p> <p>(b) Target 2, Layout No.6. Impact at normal across wing.</p>	<p>3 cuts, 4 ft, 3 ft and 2 ft (80% of chord) in upper surface skinning (14 SWG). 6 stringers severed + 1 x 50% cut. Traces of scoring on skin.</p> <p>12 ft out (100% chord) in upper surface skinning. Stringers and webs almost completely severed. Continuous row of fragment holes across lower surface skinning. 8 stringers severed, the remainder between 50% and 80% severed. Front spar web out to full depth. 8 'shatter' cracks approx. 9 ins long in lower surface skinning (Fig.15).</p>	<p>100% 'A'</p> <p>100% 'A'</p>
<p>6. <u>Lancaster Fuselage.</u></p> <p>(a) Target 1, Layout No.4. Impact at normal across fuselage.</p> <p>(b) Target 2, Layout No.4. Impact at 45° to normal across fuselage.</p>	<p>2 cuts, 42 ins and 14 ins (20% of circumference) in skinning (22 SWG). 9 stringers severed + 7 x 50% cut (35% of total). Flange of starboard longeron severed. Port longeron holed. Turret frame 75% severed. Fragment holes over 6 ft fuselage length.</p> <p>2 cuts, 78 ins and 16 ins (30% of circumference) in skinning. 12 stringers severed + 2 x 50% cut (35% of total). Starboard longeron severed.</p>	<p>Not Structurally lethal.</p> <p>100% 'A'</p>

TABLE I (Contd)

Target	Damage	A/C Kill Assessment
7. <u>Lancaster Wing.</u>		
(a) Target 3, Layout No. 3. Tank Empty. Impact at normal across wing.	15 ft cut (100% chord) in upper surface skinning (L.E. 18 SWG, interspar 18 SWG and T.E. 24 SWG). Fragment holes across lower surface skin. 18 stringers severed (90% of total). $\frac{1}{4}$ in. groove in R.S. and F.S. upper booms. Tank upper lining severed.	Not Structurally lethal.
(b) Target 1, Layout No. 5. Tank Empty. Impact at normal across wing.	10 ft cut (100% in upper surface skinning in interspar region. 21 in. cut (88%) in L.E. T.E. not fitted. Fragment holes in lower surface skin. 14 stringers severed + 3 x 50% cut (80% of total). $\frac{1}{4}$ in. groove in F.S. upper boom. F.S. lower boom 40% severed. R.S. upper boom $3\frac{1}{2}$ in. x 1 in. removed. R.S. lower boom 1 in. x $\frac{1}{2}$ in. removed. Hole 9 in. x 4 in. in F.S. web.	50% 'A'
(c) Target 4, Layout No. 3. Tank $\frac{7}{8}$ filled water. Impact at normal across wing.	10 ft cut (100%) in upper surface skinning in interspar region, with skinning bulged up to 3 in. over 4 ft span. T.E. skinning 100% severed. L.E. skinning 90% severed. No damage to lower surface skinning in tank area, fragment holes in L.E. and T.E. 10 stringers severed (50% of total). $\frac{1}{4}$ in. groove in F.S. upper boom. $\frac{1}{4}$ in. groove in R.S. upper boom. 4 in. gash in R.S. web. 3 upper surface spanwise joints opened, 12 ins, 18 ins and 24 ins.	Not Structurally lethal.

R.S. = Rear spar.

F.S. = Front spar.

TABLE I (Contd)

Target	Damage	A/C Kill Assessment
7. <u>Lancaster Wing (Contd)</u>		
(d) Target 3, Layout No.5. Tank $\frac{7}{8}$ filled water. Impact at normal across wing.	10 ft out (100%) in upper surface skinning in interspar region, with skinning bulged up to 12 ins over 5 ft span, with joint opened. 24 in. out in L.E. upper skinning. 15 in. out in L.E. lower skinning. T.E. not fitted. No damage to lower surface skinning in tank area. 10 stringers severed (50% of total). $\frac{1}{4}$ in. groove in F.S. upper boom. $\frac{1}{4}$ in. groove in R.S. upper boom. F.S. lower boom 20% damaged.	Not Structurally lethal.
(e) Target 2, Layout No.5. Tank Empty. Impact at 60° to normal across wing.	10 ft out (100%) in upper surface skinning in interspar region. 13 in. out in L.E. skinning. T.E. not fitted. 7 stringers severed + 4 x 80% (50% of total). $\frac{1}{4}$ in. groove in F.S. upper boom. Holes 10 in. x 3 in., 3 in. x 1 in. and 2 in. x 1 in. in R.S. web.	Not Structurally lethal.
(f) Target 4, Layout No.5. Tank $\frac{7}{8}$ filled water. Impact at 60° to normal across wing.	10 ft out (100%) in upper surface skinning in interspar region. 19 in. out in L.E. skinning. 10 stringers severed (50% of total).	Not Structurally lethal.
(g) Target 6, Layout No.6. Tank Empty. Impact at 79° to normal across wing.	10 ft out (100%) in upper surface skinning in interspar region. 12 in. out in L.E. skinning. 1 stringer severed + 9 x 60% cut (30% of total). 15 in. ricochet score on skinning.	Not Structurally lethal.
8. <u>B.29 Fuselage.</u>		
(a) Target 2, Layout No.2. Impact at normal 60° across fuselage.	13 ft out (40% of circumference) in skinning (0.040 in. and 0.051 in.). 13 stringers severed (25% of total). 4 frames severed. Fragment holes in 3 ft band on exit side of fuselage.	Not Structurally lethal.

TABLE I (Contd.)

Target	Damage	A/C Kill Assessment
8. <u>B.29 Fuselage (Contd)</u>		
(b) Target 1, Layout No.1. Impact at normal 45° across fuselage.	9 ft cut (40% of circumference) in skinning. 12 stringers severed (25% of total). 2 frames severed + 2 x 75% cut. Fragment holes in 3 ft band on exit side of fuselage.	Not Structurally lethal.
(c) Target 1, Layout No.2. Impact at normal 60° across fuselage.	7½ ft cut (35% of circumference) in skinning. 16 stringers severed + 1 x 50% cut (35% of total). 1 frame severed + 1 x 50% cut. Turret frame 75% severed. Fragment holes in 3 ft wide band on exit side of fuselage.	Not Structurally lethal.
(d) Target 2, Layout No.1. Impact at normal across fuselage.	9 ft cut (45% of circumference) in skinning. 18 stringers severed + 4 x 50% cut (45% of total). 1 frame severed. Fragment holes in 3 ft wide band on exit side of fuselage.	100% 'A'
9. <u>Replica Target R4B</u>		
(a) Target 4, Layout No.4. Impact at Normal.	2 cuts, 28 in. and 57 in. (90% chord) in skinning (6 SWG) of upper surface. 2 stringers severed + 1 x 25% + 2 x 50% + 3 x 75% cut. I-beam flange severed. (There are 9 stringers and 2 I-beams on this surface.) R.S. upper boom grooved $\frac{3}{8}$ in. deep. T.E. completely severed. Rod exit holes in lower surface up to 10 in. x 7 in. plus 3 stringers severed + 3 x 50% + 2 x 25% cut (40% of total).	Not Structurally lethal.
(b) Target 5, Layout No.4. Impact at Normal.	96 in. cut (100% chord) in lower surface skinning (6 SWG). 11 stringers severed (100%) + 1 I-beam severed + 1 I-beam 25% cut. I-beam split longitudinally for 3 ft span. Centre joint opened for 3 ft span. $\frac{1}{4}$ in. groove in R.S. lower boom. Fragment holes in upper surface.	Not Structurally lethal.

TABLE I (Contd)

Target	Damage	A/C Kill Assessment
10. <u>Spitfire Wing.</u>		
(a) Target 3, Layout No.1. Impact at normal across wing from 45° below ahead.	L.E. skin (14 SWG) almost completely cut. Cut continuous in lower surface to flaps. 30 in. cut in upper surface at rear of wing. $\frac{1}{4}$ in. groove in main spar lower boom. $\frac{1}{4}$ in. vertical cut on M.S. top boom. Aileron spar severed. Rib 25% cut. Hole 4 in. x 3 in. in upper surface aft of spar.	100% 'A'
(b) Target 4, Layout No.1. Impact at normal across wing from dead ahead.	3 in. cut in L.E. upper skinning (14 SWG). 3 in. cut in L.E. lower skinning (14 SWG). Skin petalled 3 in. outwards on one side.	Not Structurally lethal.
(c) Target 3, Layout No.2. Impact at normal across wing from dead ahead.	8 in. cut in L.E. upper skinning. 4 in. cut in L.E. lower skinning.	Not Structurally lethal.
(d) Target 4, Layout No.4. Impact at normal across wing from 10° above dead ahead.	18 in. cut from L.E. to spar in top surface then 8 in. cut to tank panel, 20 in. score across tank panel, then 28 in. cut to within 5 ins of T.E. 1 in. spanwise cut $\frac{1}{4}$ in. deep in top boom. 13 in. x 4 in. hole in bottom surface. Spar bottom boom 30% out. 5 in. spanwise split in spar web.	100% 'A'

M.S. = Main spar.

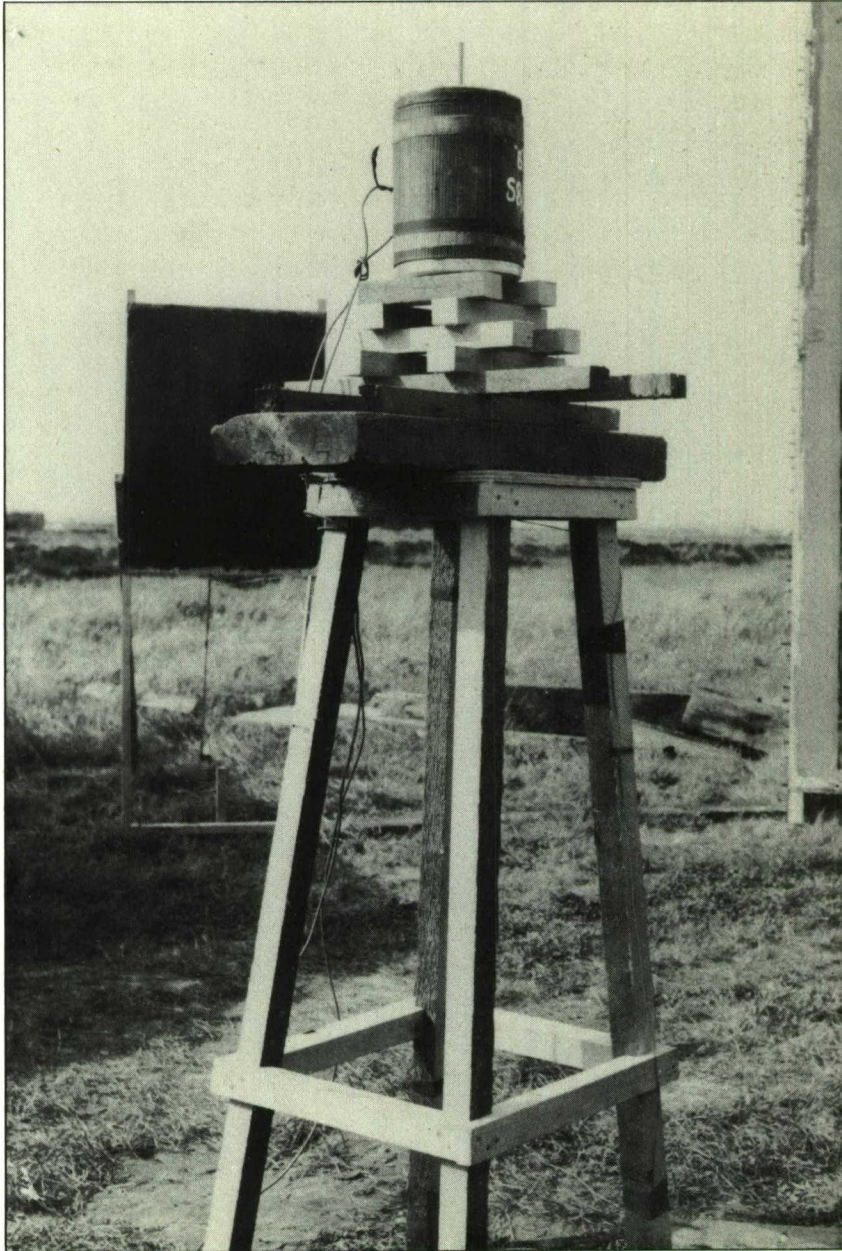


FIG. I. WARHEAD BEFORE DETONATION

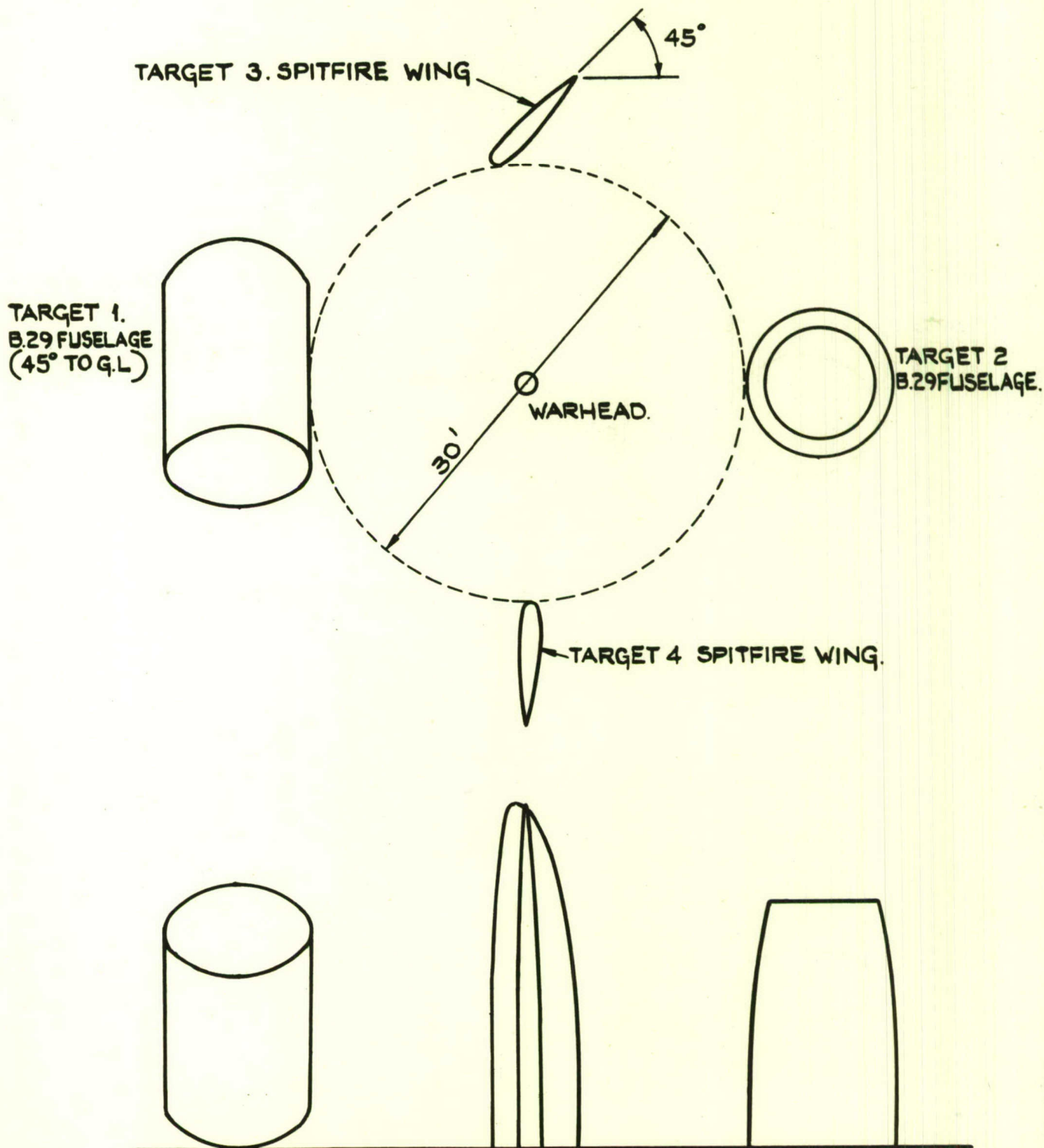


FIG. 2. TARGET LAYOUT No. 1.

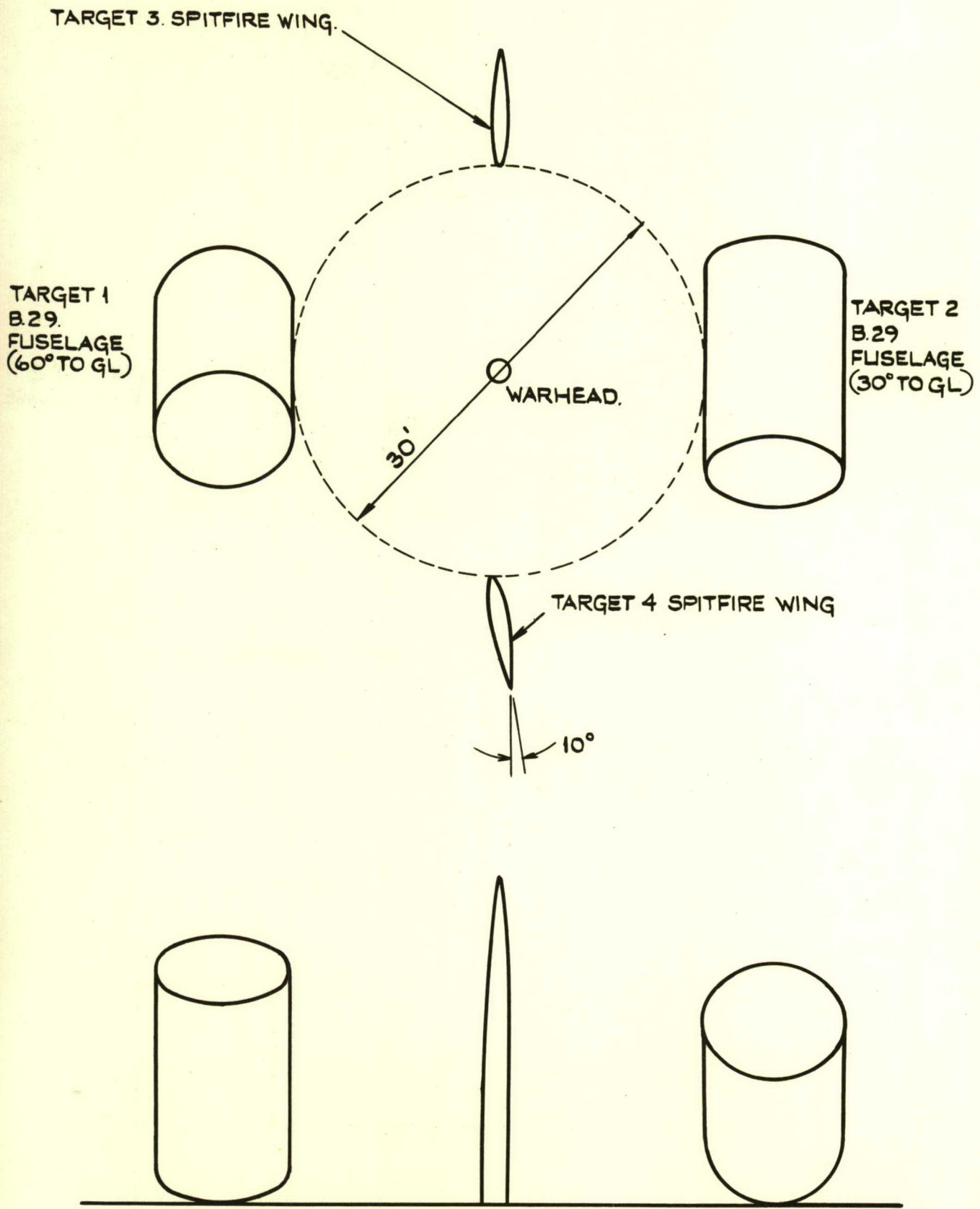


FIG. 3. TARGET LAYOUT No. 2.

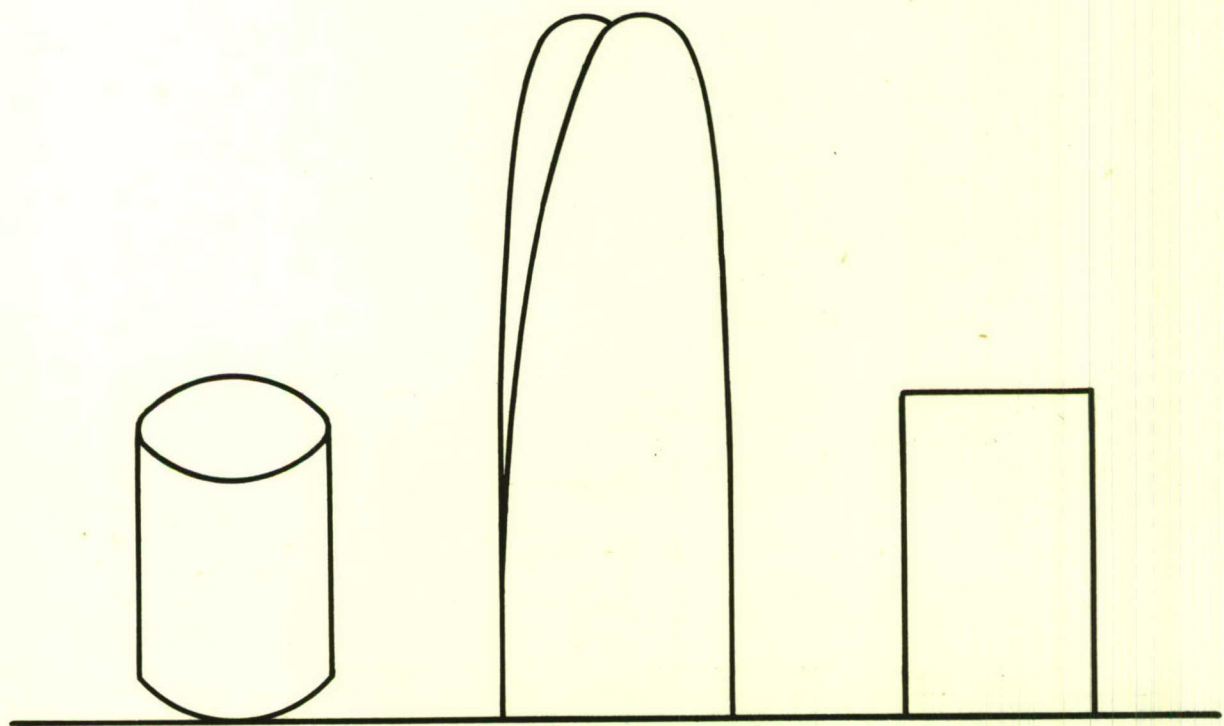
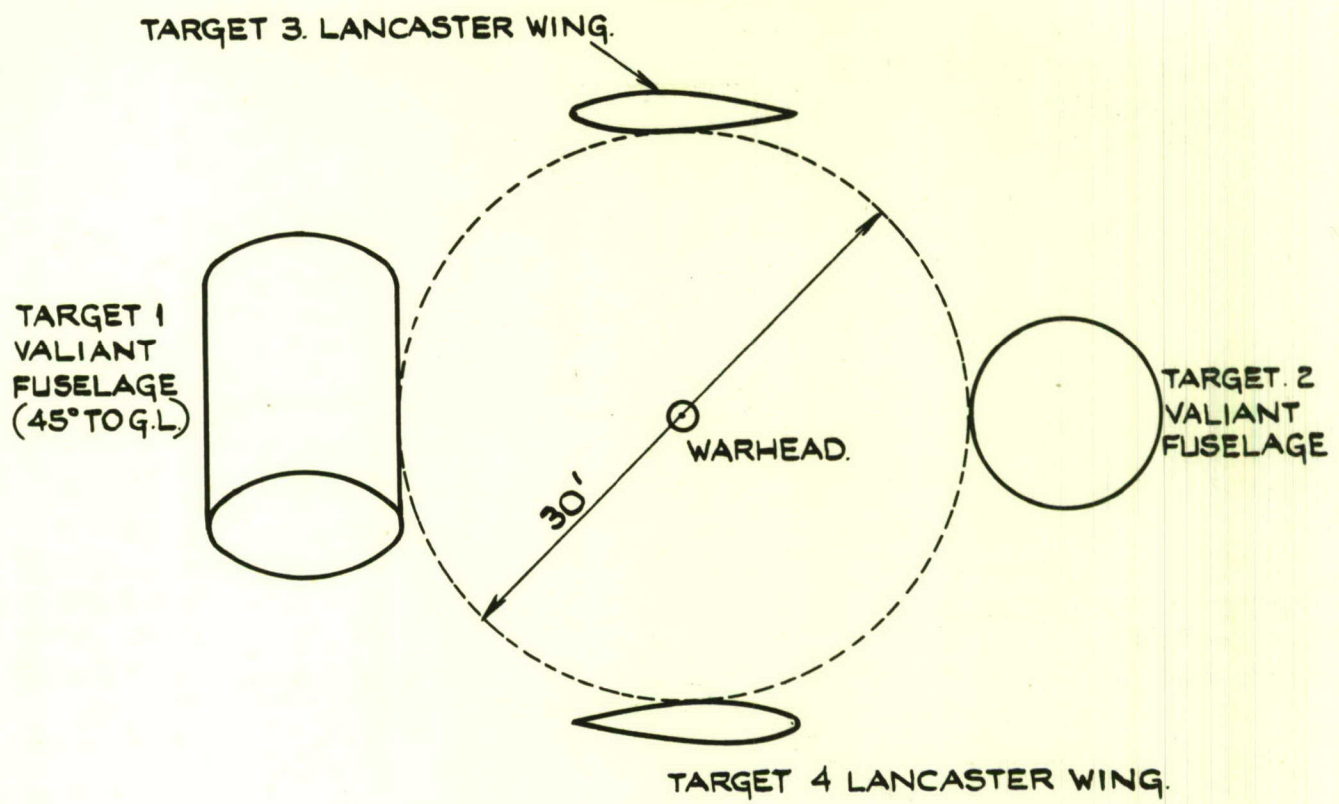


FIG.4. TARGET LAYOUT No.3.

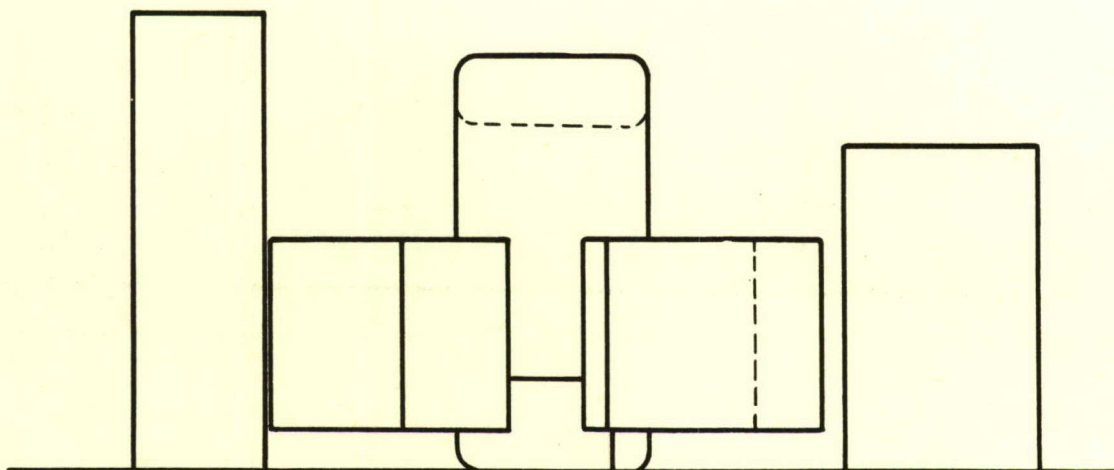
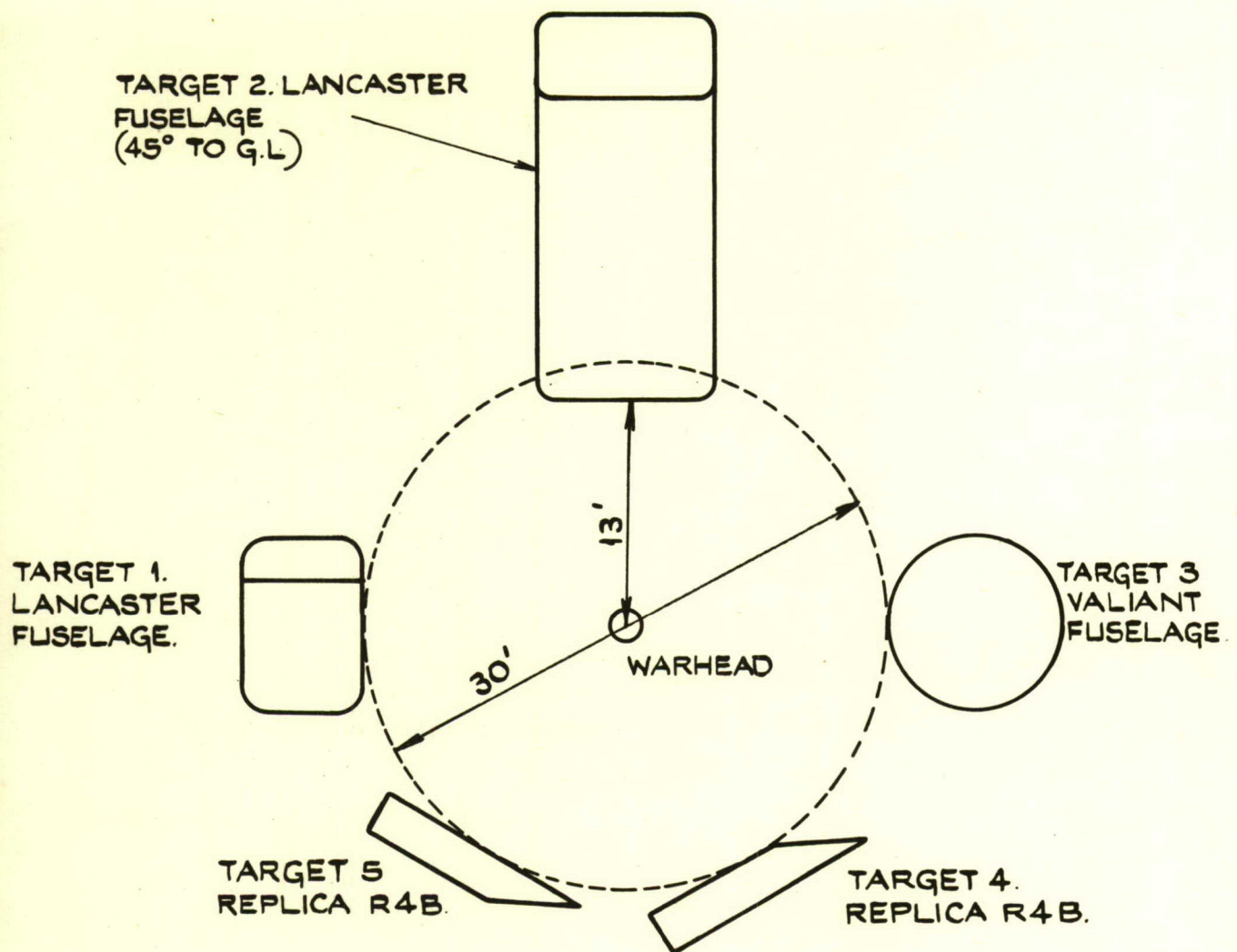


FIG. 5. TARGET LAYOUT No. 4.

TARGET 1 LANCASTER WING.

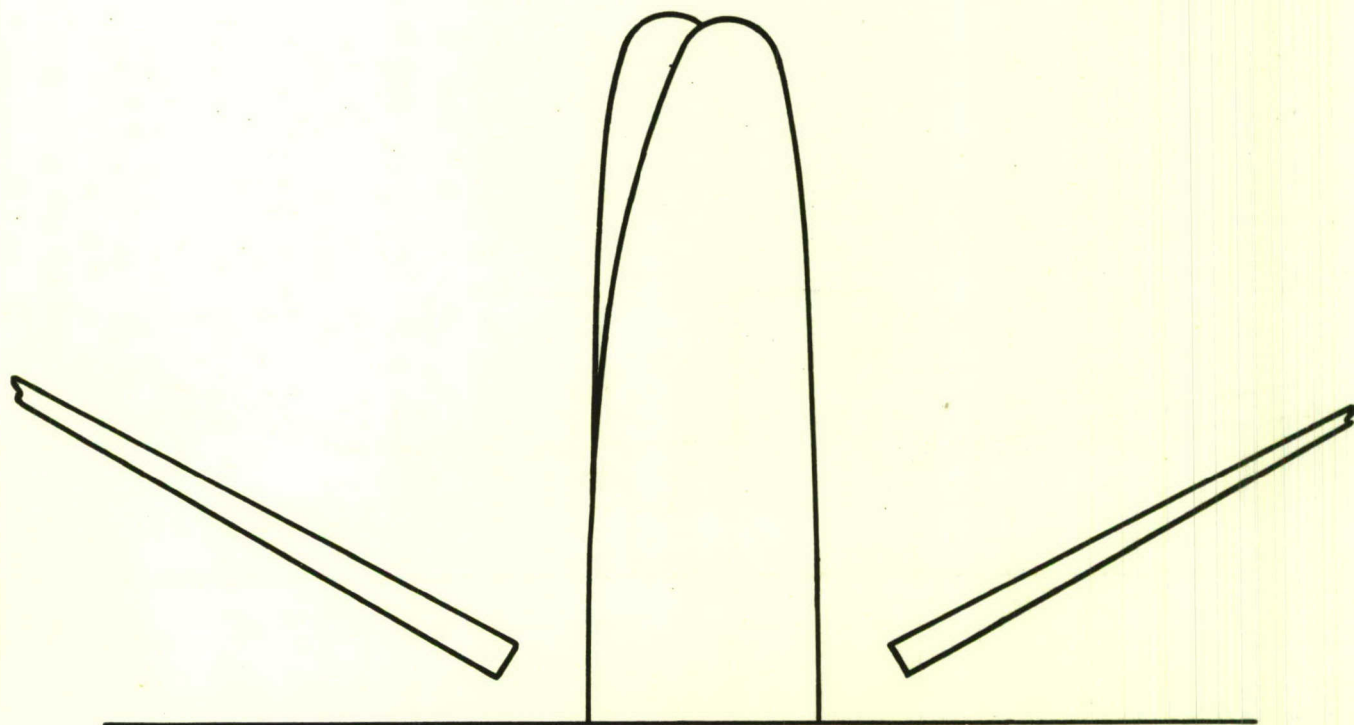
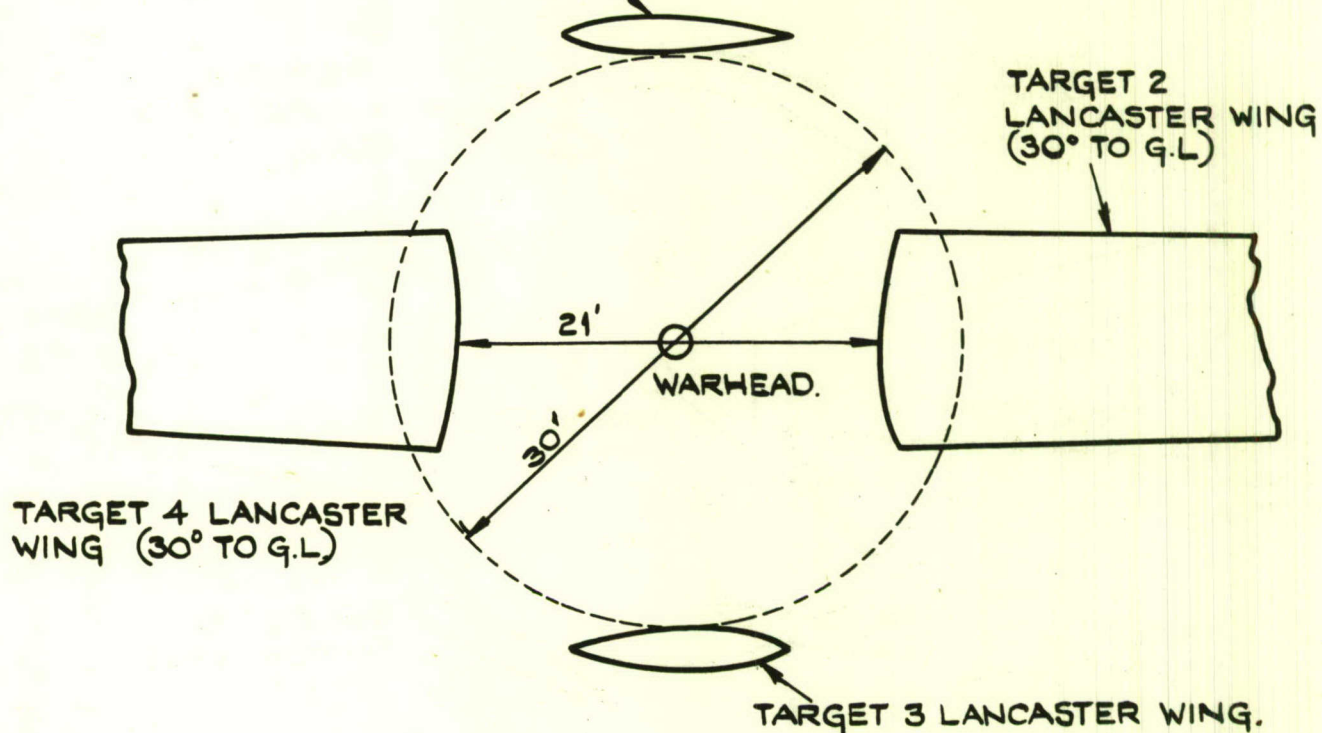


FIG .6. TARGET LAYOUT No. 5.

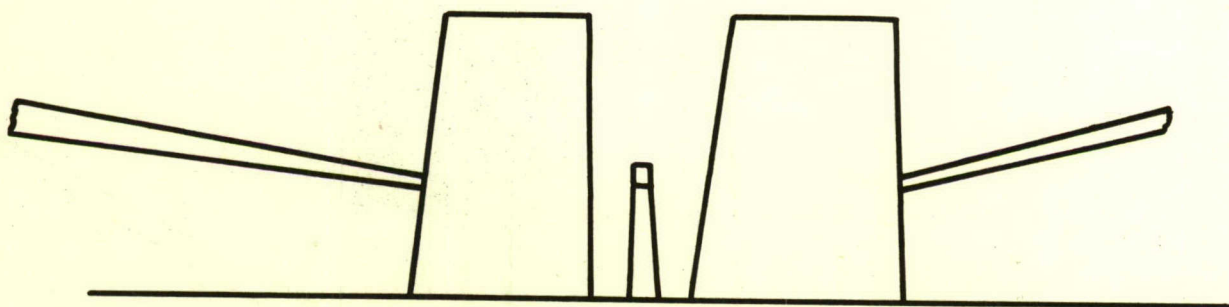
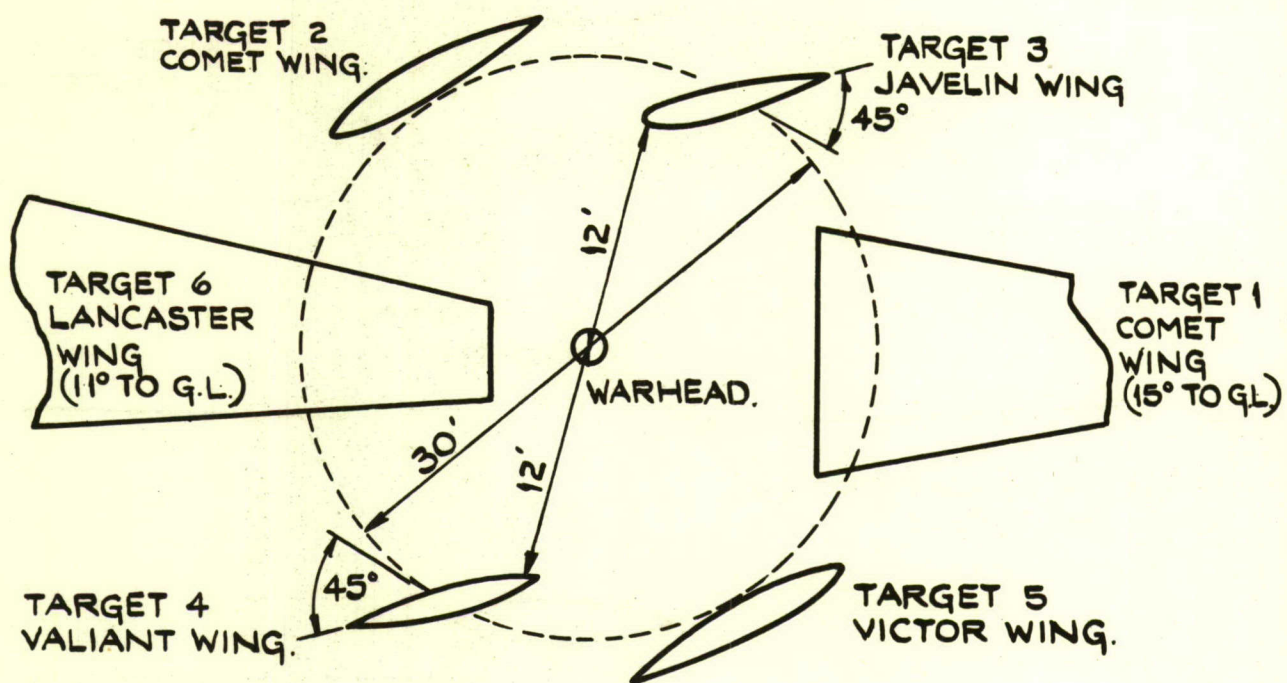


FIG. 7. TARGET LAYOUT No. 6.

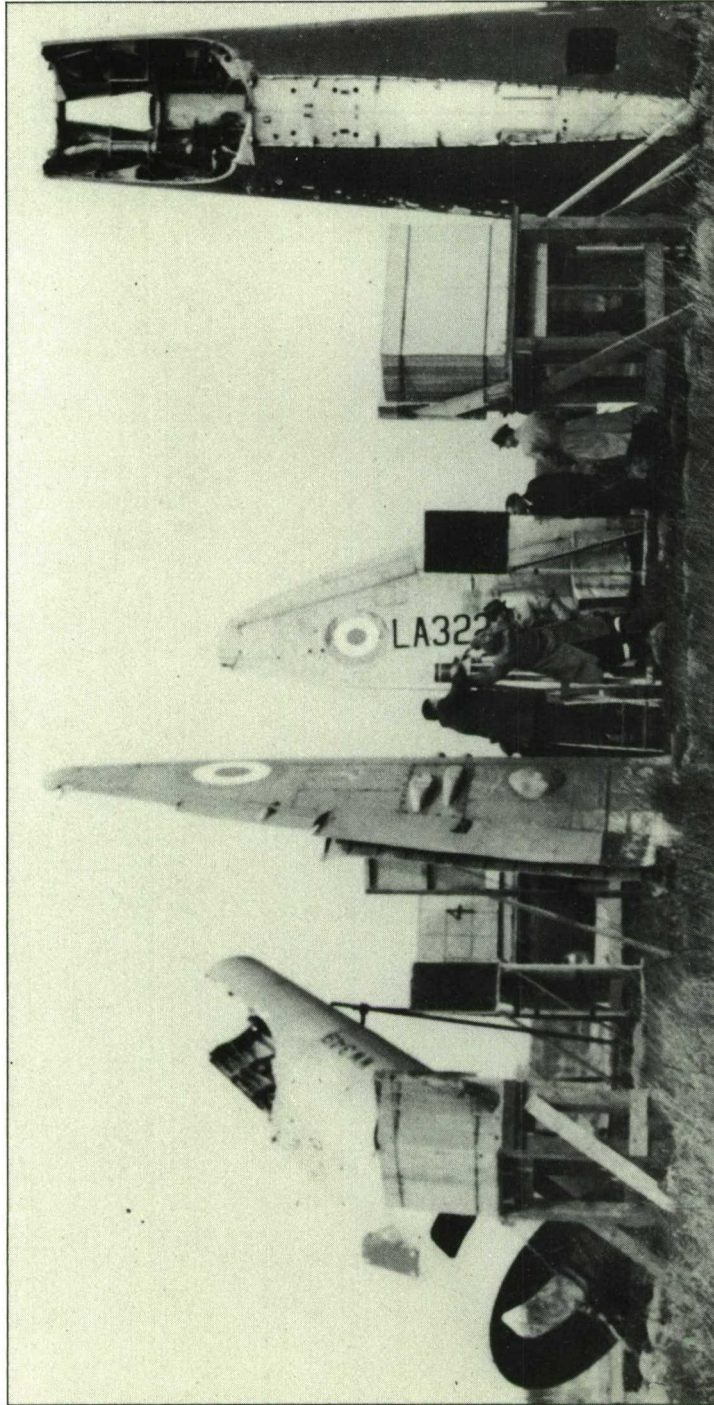


FIG.8. TARGET LAYOUT No.1 BEFORE FIRING

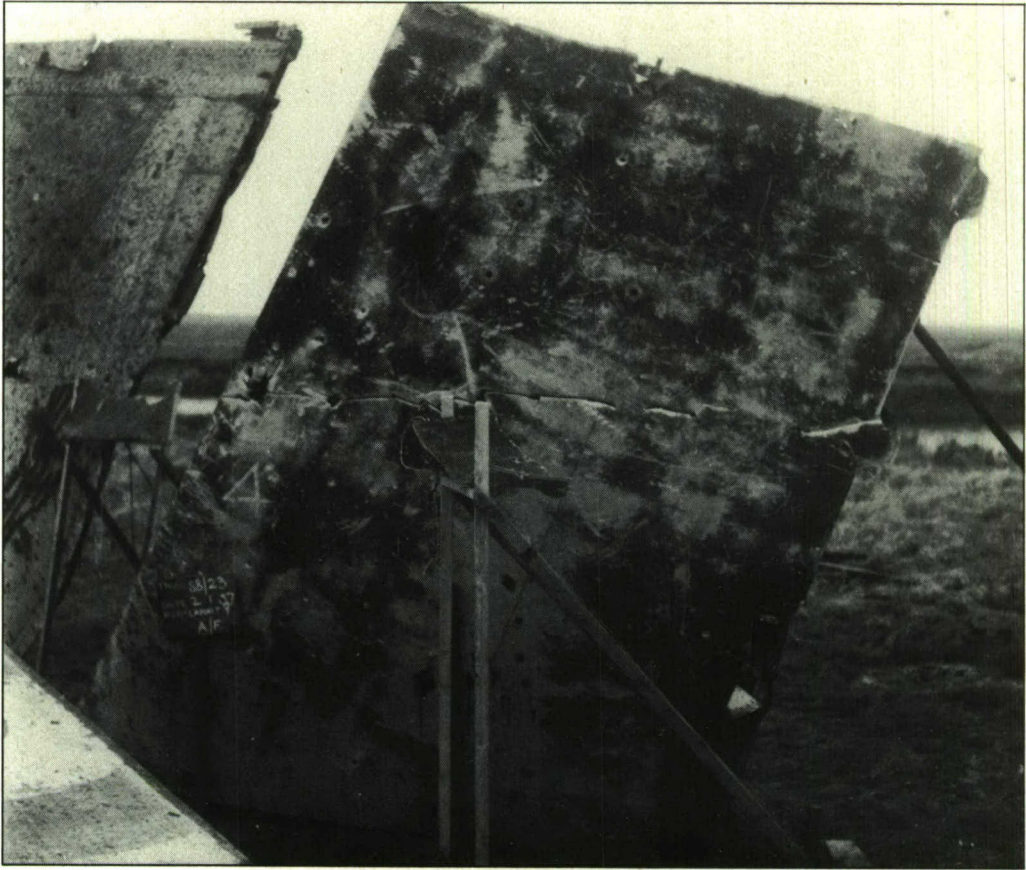


a. ROD ENTRY

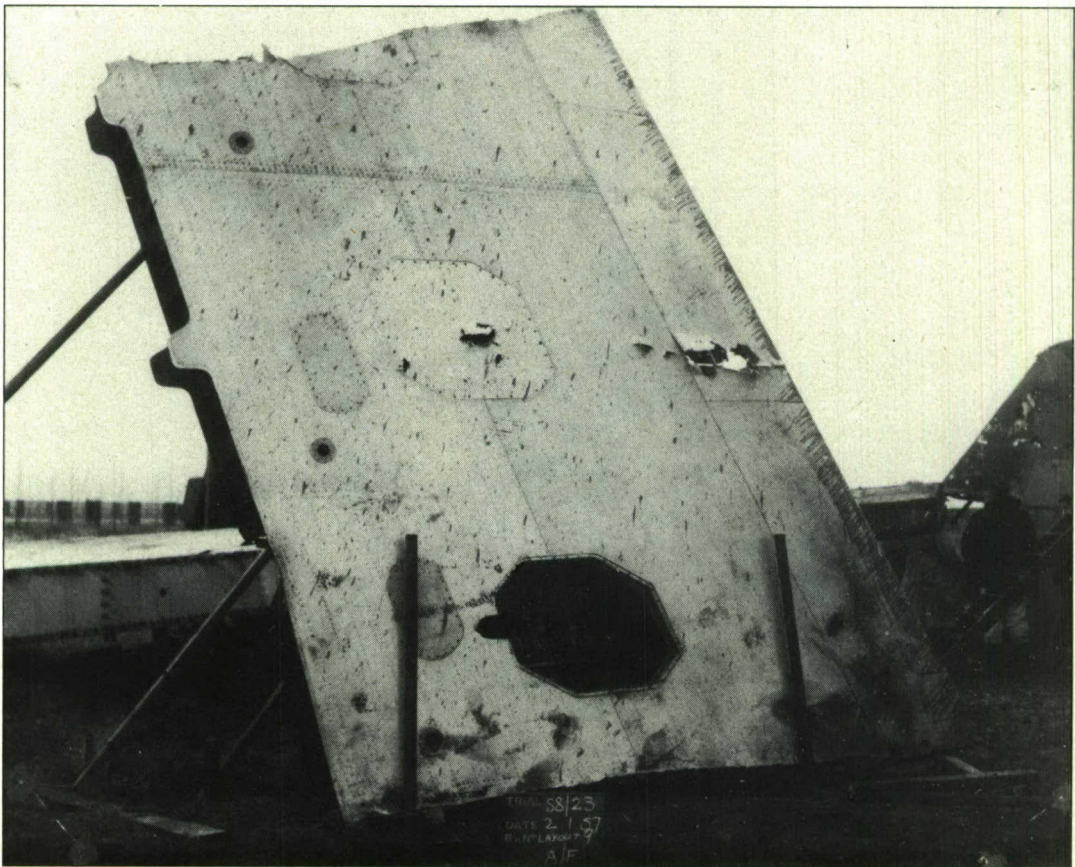


b. ROD EXITS

FIG.9. VALIANT FUSELAGE AT 45° TO THE PLANE OF RODS. (TABLE I, I a)



a. ROD ENTRY

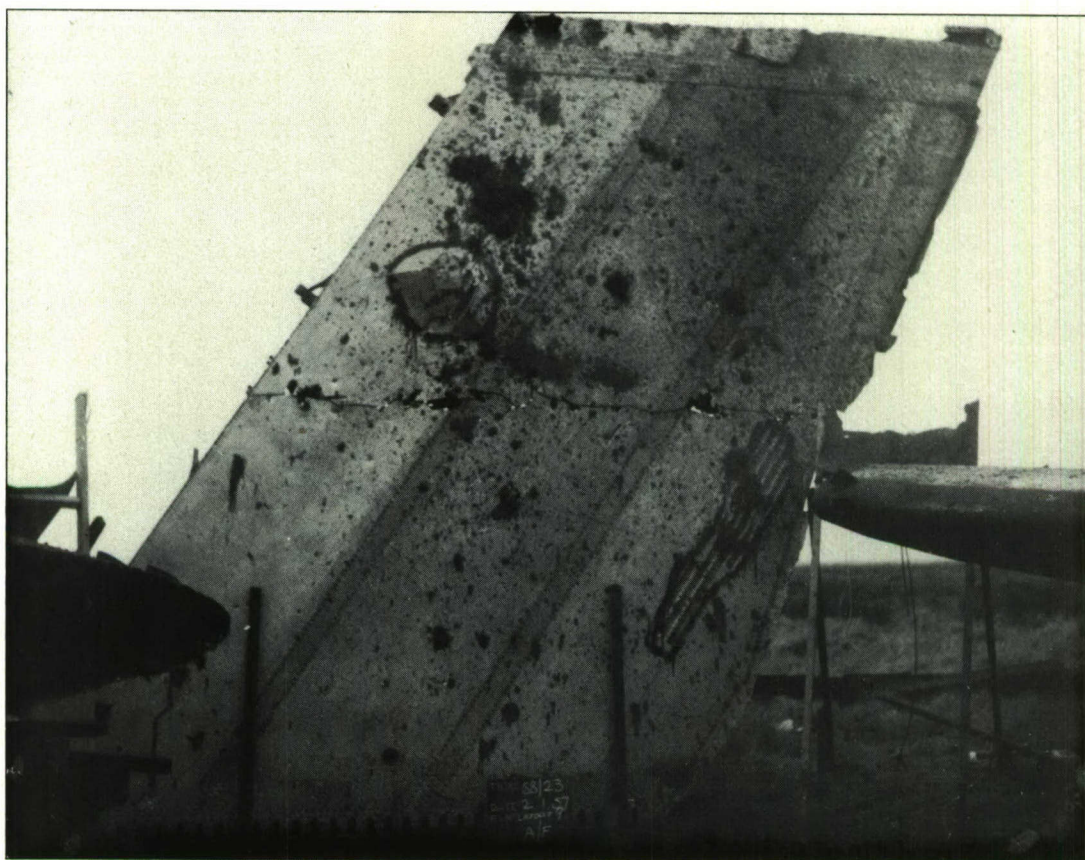


b. ROD EXITS

FIG.10. VALIANT WING, AT 90° TO THE PLANE OF RODS (TABLE I, 2 a)



a. BEFORE DETONATION



b. AFTER DETONATION, ROD ENTRY

FIG.11. VICTOR WING AT 90° TO THE
PLANE OF RODS (TABLE I, 3 a)

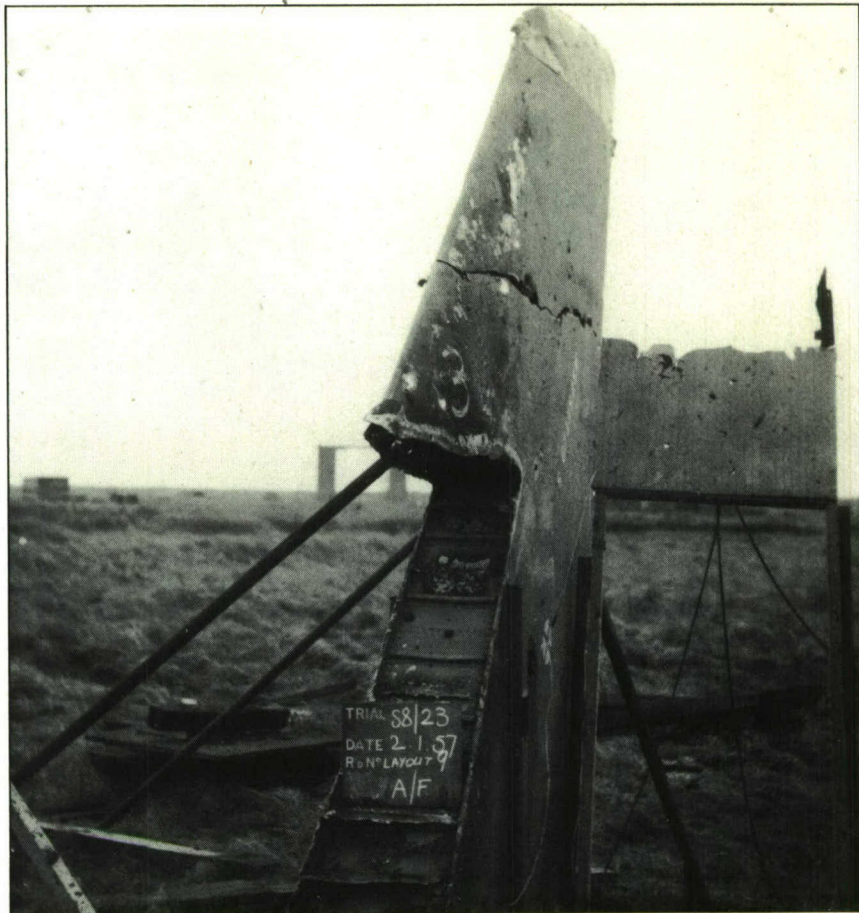


a. BEFORE DETONATION

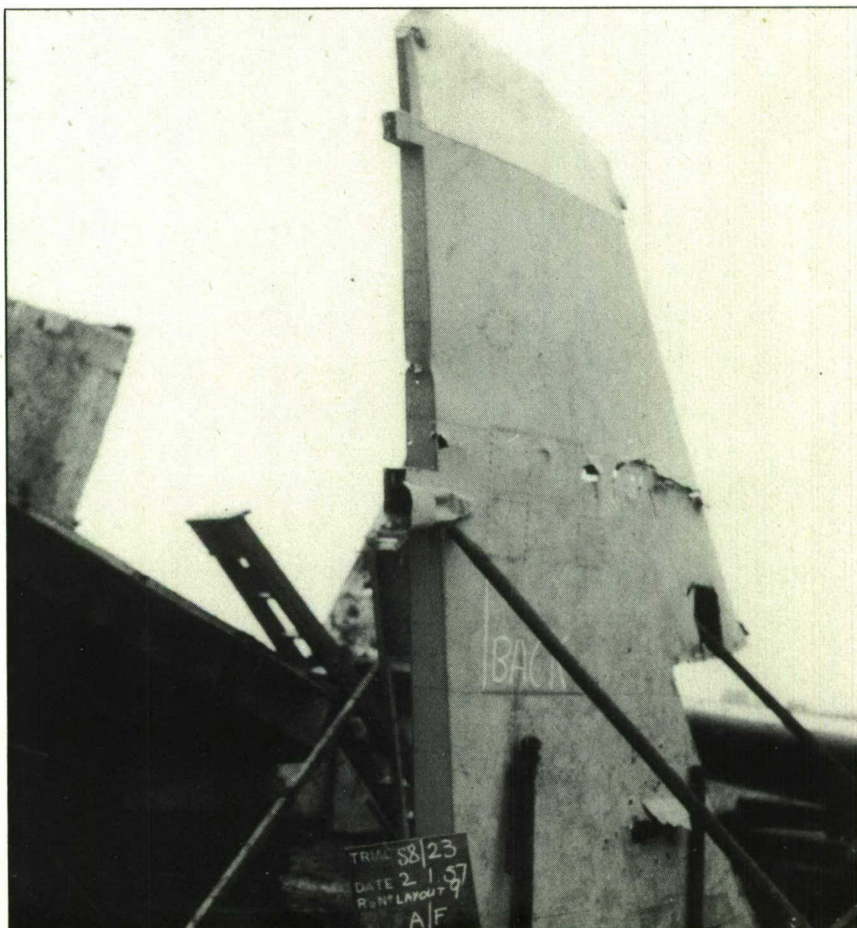


b. AFTER DETONATION, ROD EXITS

FIG.12. VICTOR WING AT 90° TO THE
PLANE OF RODS (TABLE 1, 3 a)

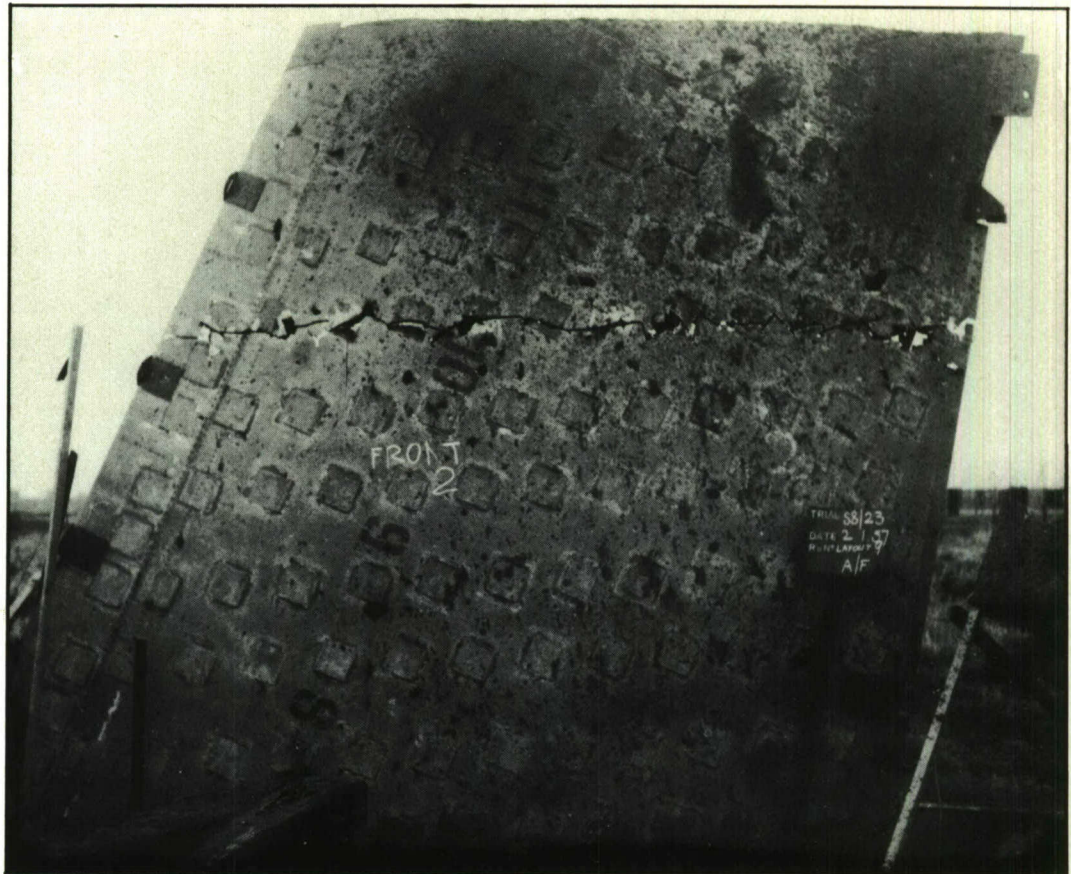


a. ROD ENTRY

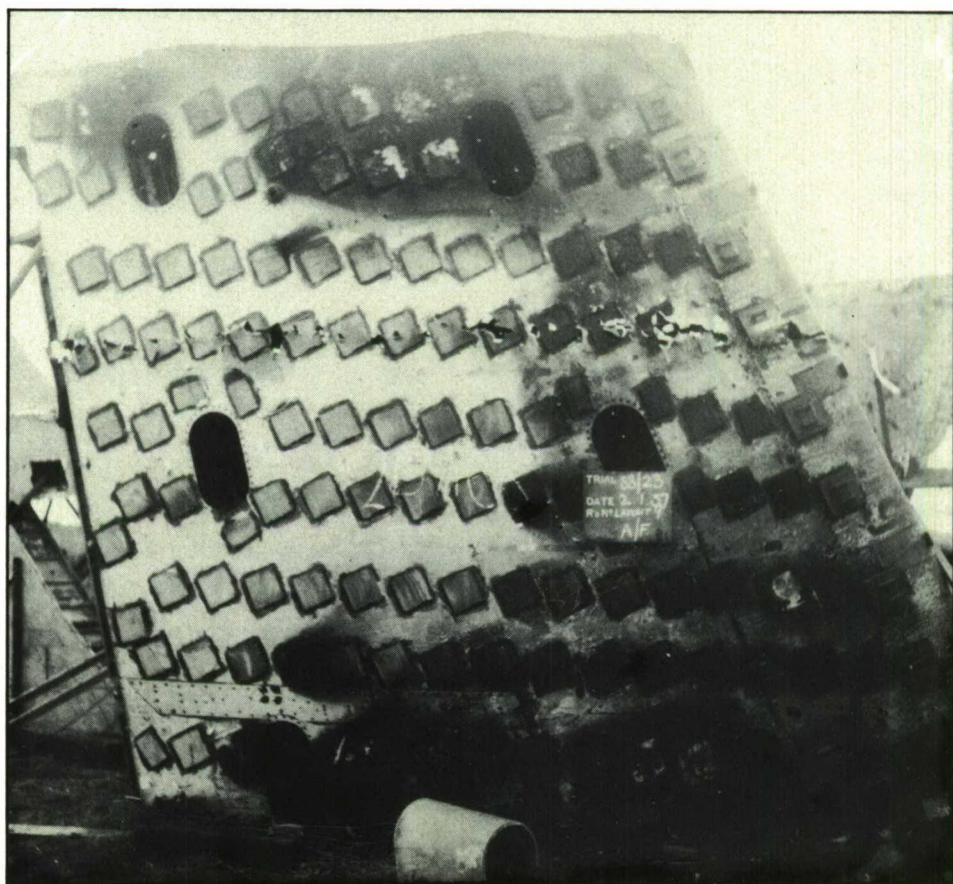


b. ROD EXITS

FIG.13. JAVELIN WING AT 90° TO THE PLANE OF RODS (TABLE I, 4 a)



a. ROD ENTRY

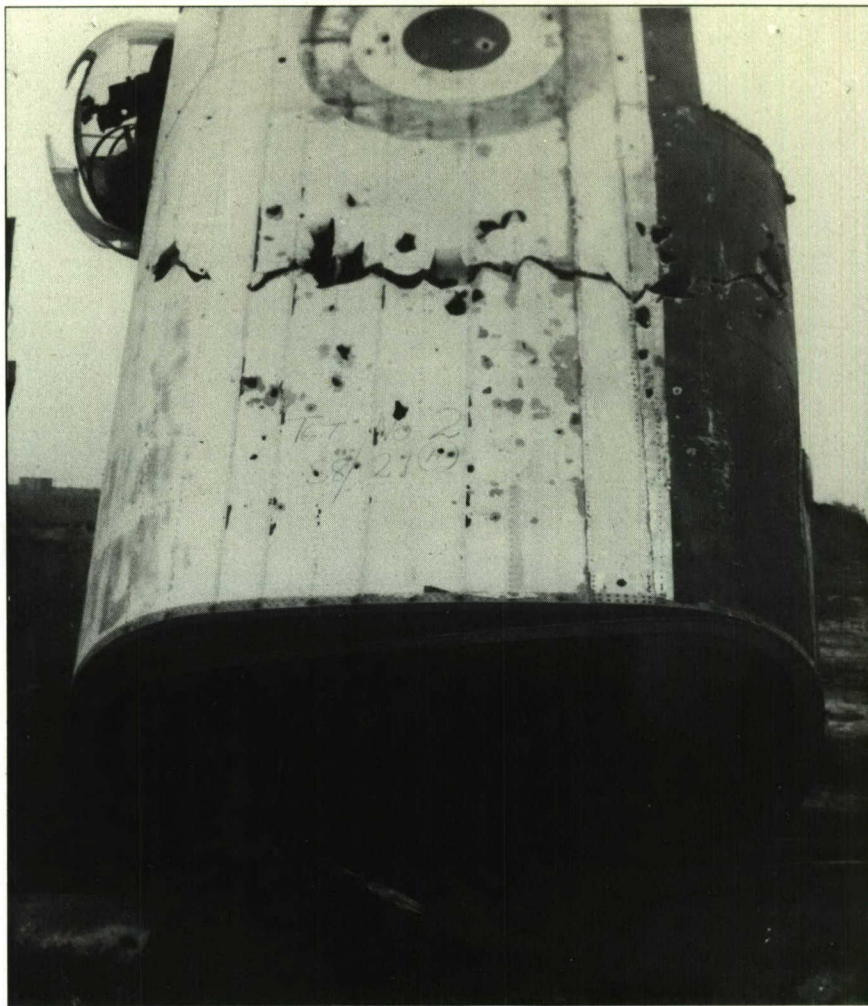


b. ROD EXITS

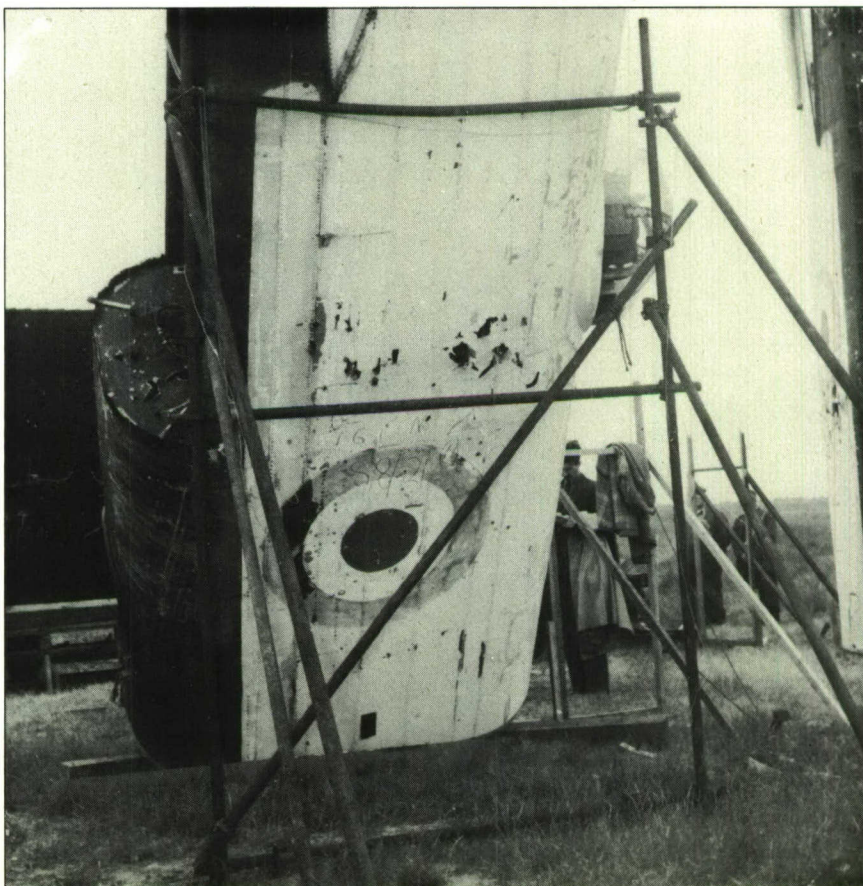
FIG.14. COMET WING AT 90° TO THE PLANE OF RODS (TABLE I, 5b)



FIG.15. SHATTER CRACKS IN COMET WING.
(TABLE I, 5b)

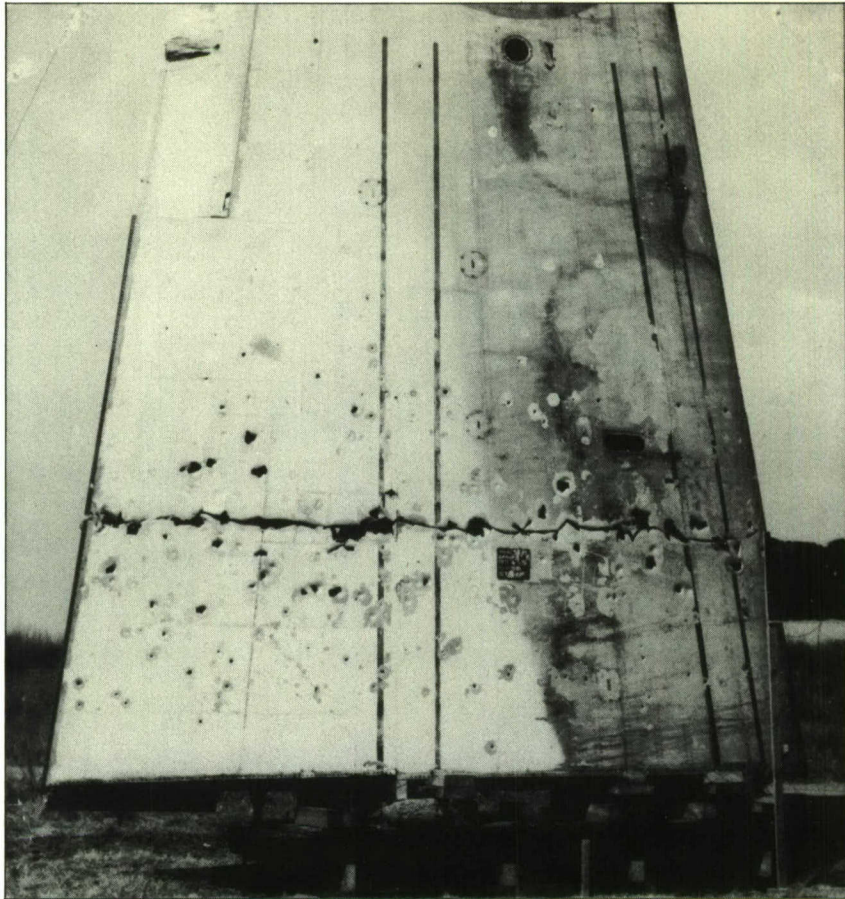


a. ROD ENTRY

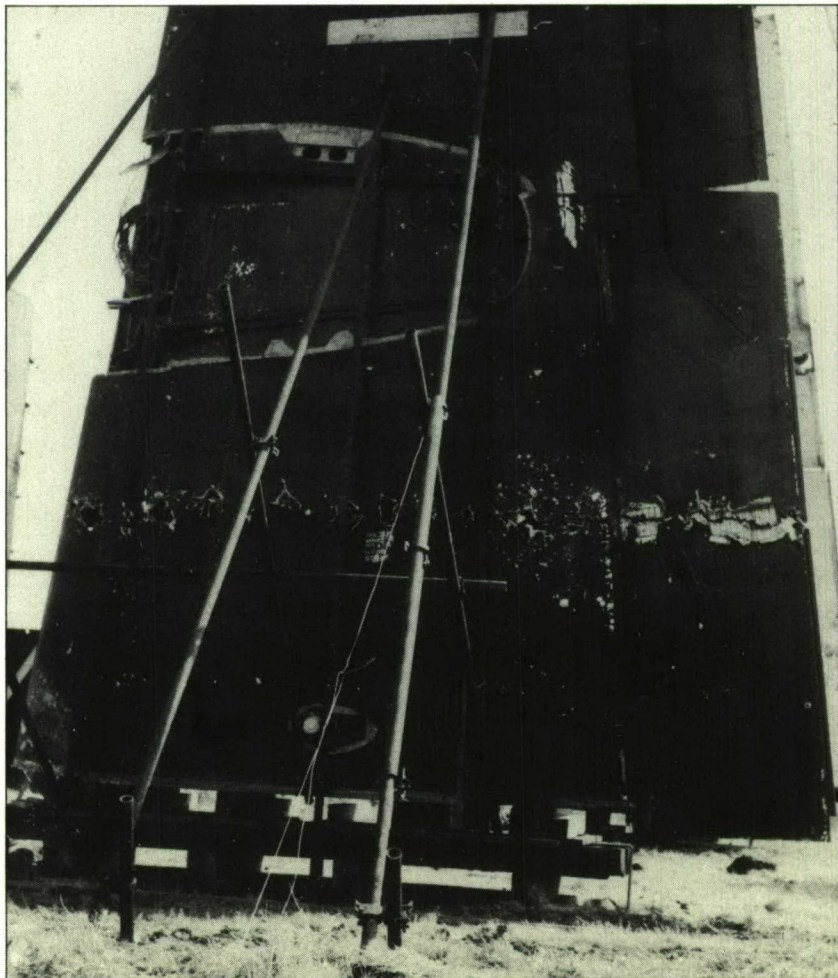


b. ROD EXITS

FIG.16. LANCASTER FUSELAGE AT 45° AWAY FROM PLANE OF RODS (TABLE I, 6b)

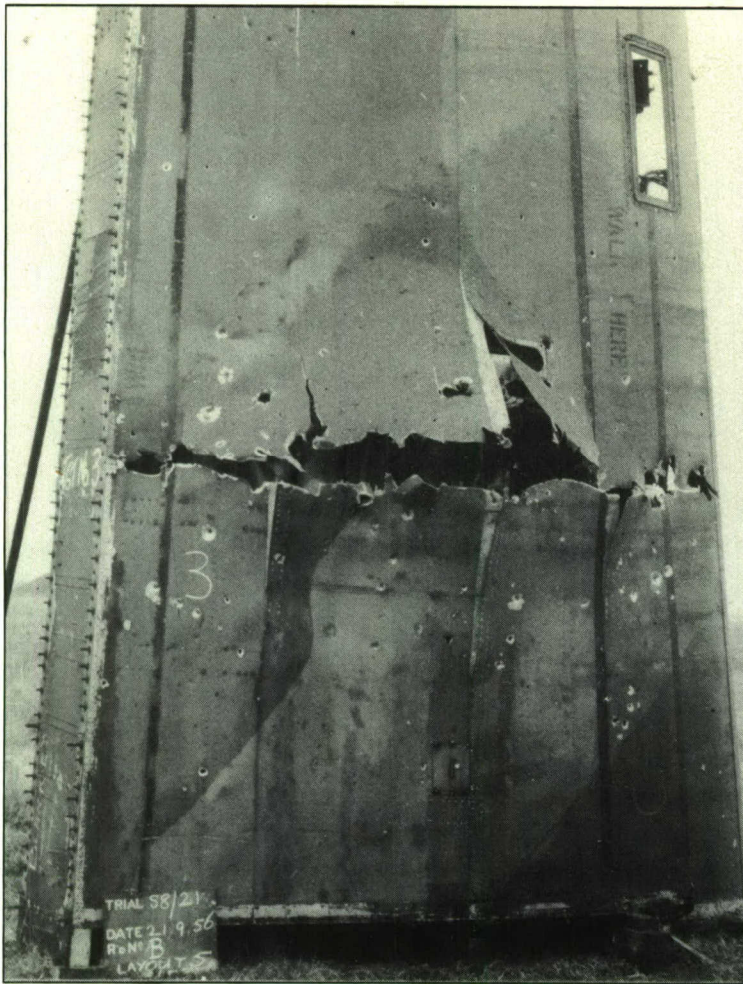


a. ROD ENTRY



b. ROD EXITS

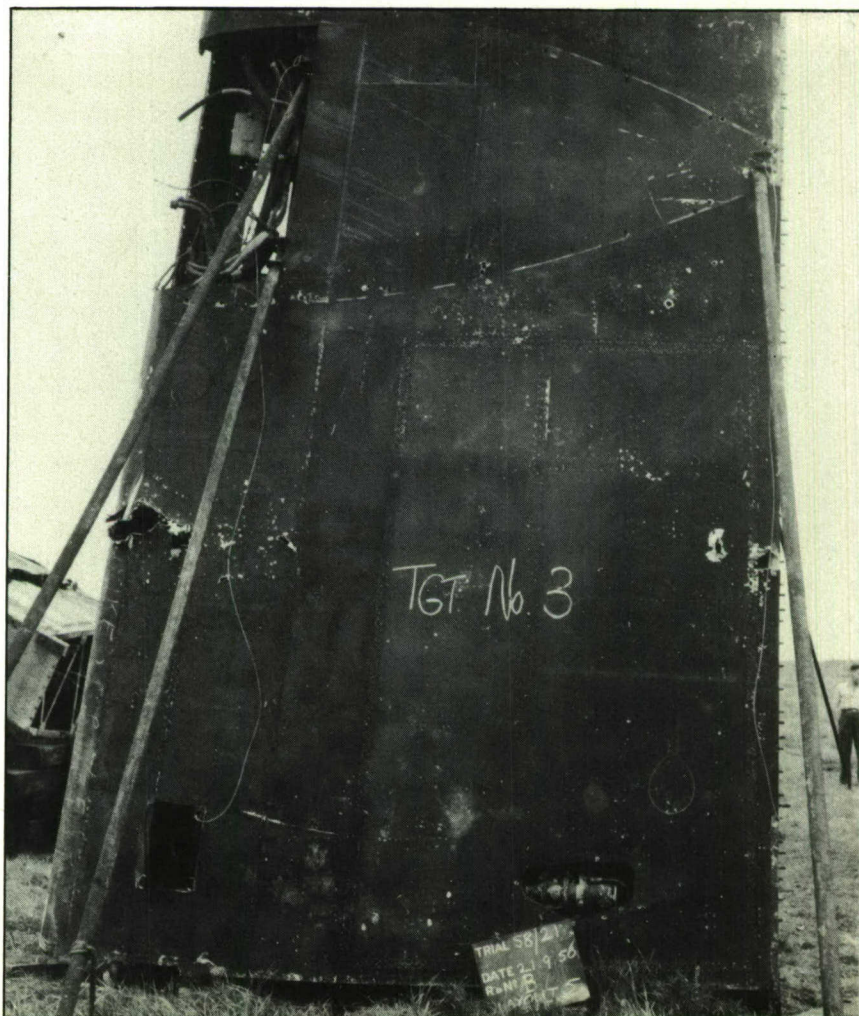
FIG.17. LANCASTER WING (TANK EMPTY) AT 90° TO THE PLANE OF RODS (TABLE I, 7a)



a. ROD ENTRY, FRONT VIEW

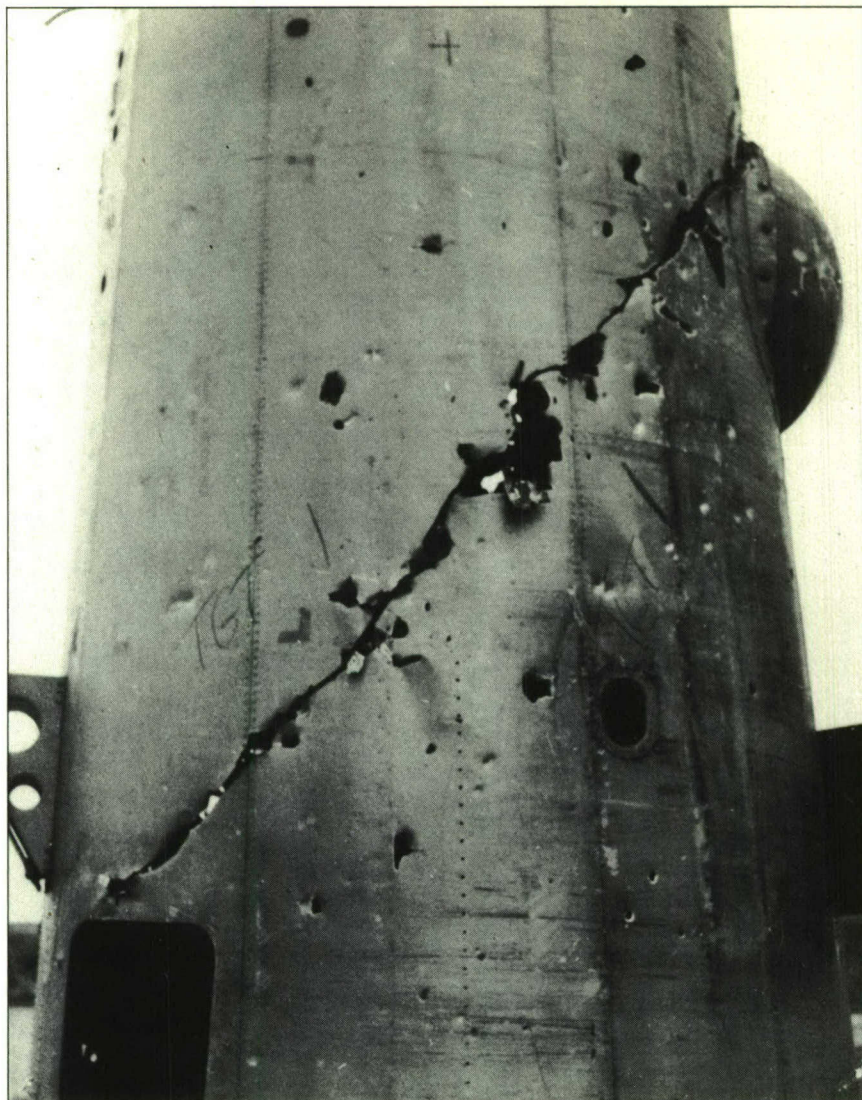


b. ROD ENTRY, SIDE VIEW

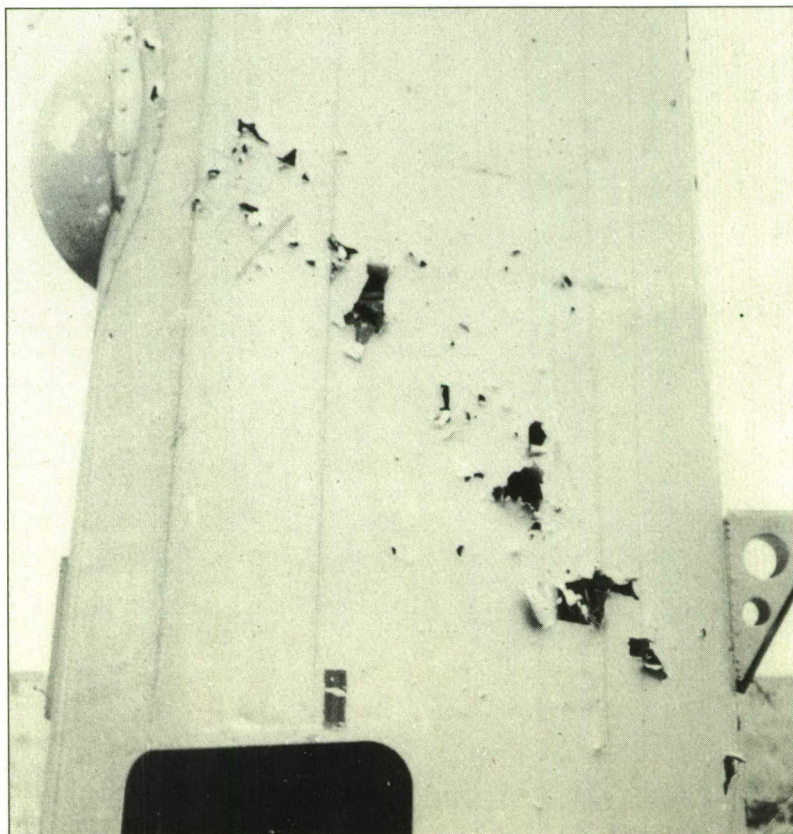


c. ROD EXITS

FIG. 18. LANCASTER WING (TANK SEVEN-EIGHTS FILLED WATER)
AT 90° TO THE PLANE OF RODS (TABLE I, 7d)



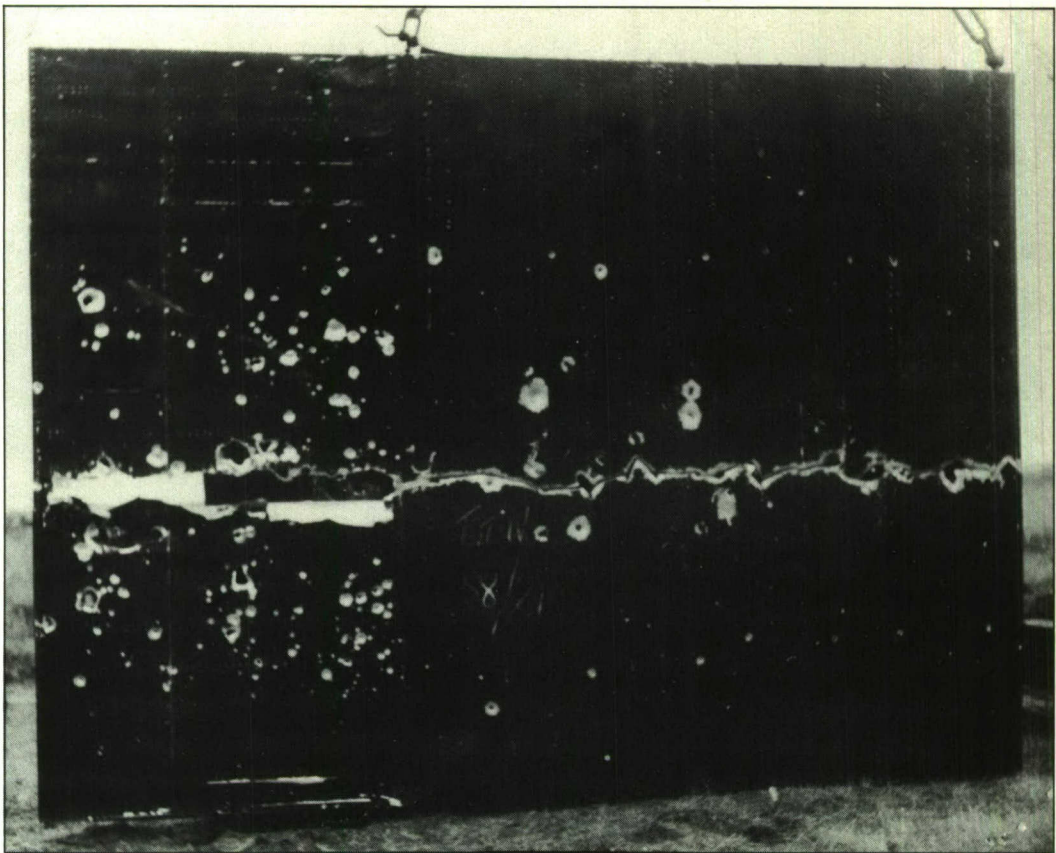
a. ROD ENTRY



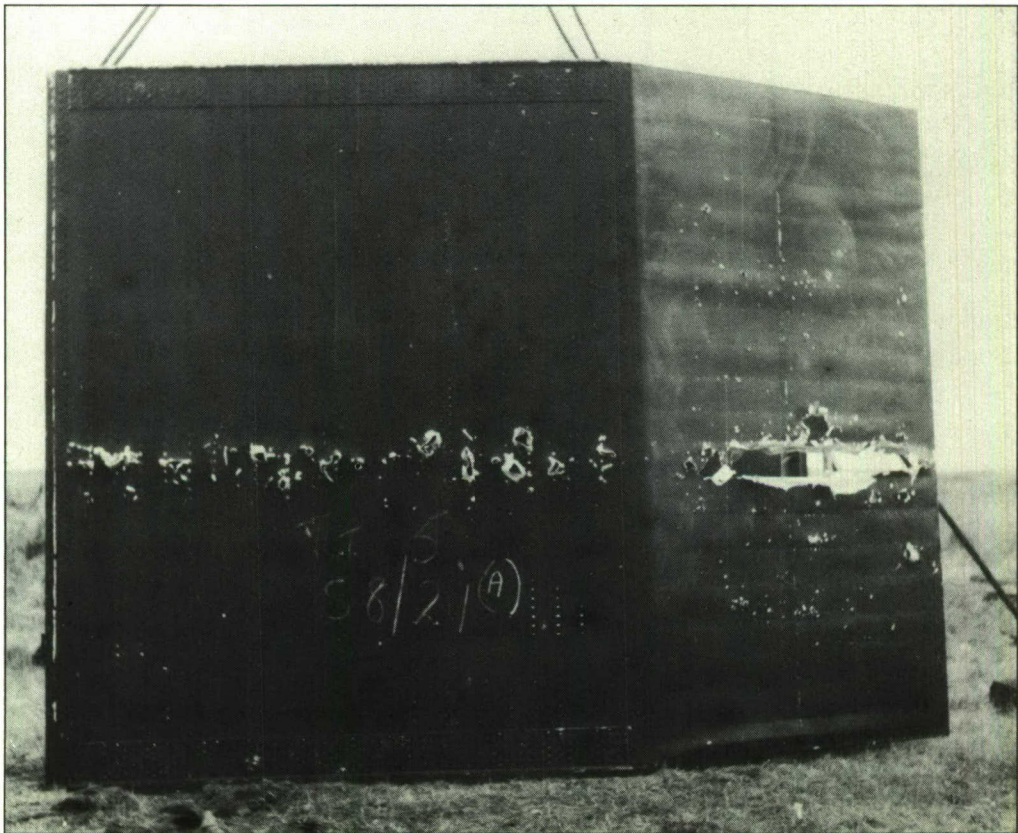
b. ROD EXITS

FIG.19. B.29. FUSELAGE AT 45° TO THE
PLANE OF RODS (TABLE I, 8b)

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a. ROD ENTRY



b. ROD EXITS

FIG.20. REPLICA TARGET R4B AT 90° TO THE PLANE OF RODS (TABLE I, 9b)

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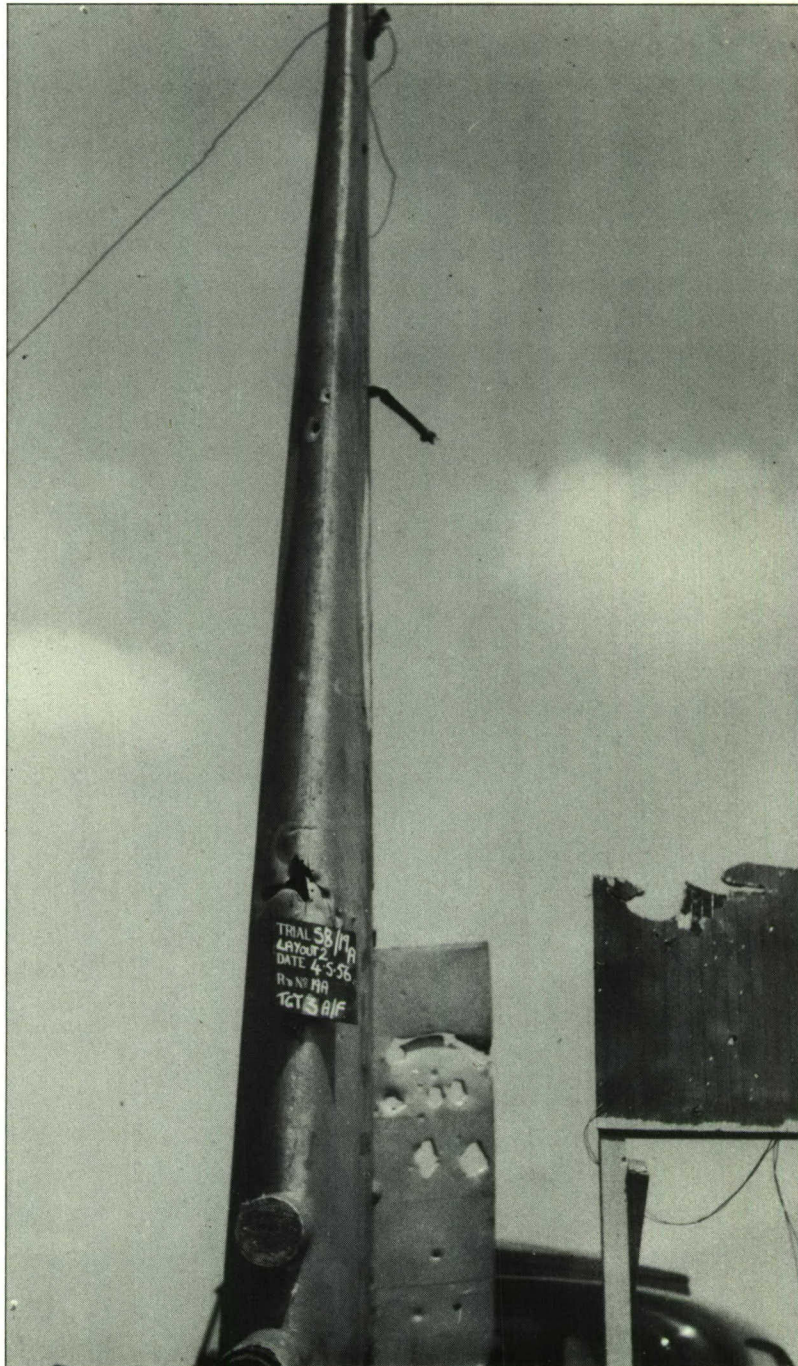


FIG.21. SPITFIRE WING, L.E. TOWARDS WARHEAD. (TABLE I, 10c)

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623.4.082.5:
623.562.1:
623.562.5:
629.13

This Note records the results of six static detonations of continuous-rod warheads (rod cross-section 3/16 inch x 3/16 inch) against aircraft targets at ground level. An indication of the kill probabilities against aircraft structures is given. The warhead appears to be more damaging against structures with distributed load-carrying members than against those with concentrated primary structural members. In general, the standard of terminal lethality of the warhead does not seem sufficiently high for a front-line defence weapon.

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